Hysteresis in the transition between hard and soft spectral state of low-mass X-ray binaries

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Abstract. An interesting feature found in X-ray binary observations is the change between a soft and a hard spectrum. Such transitions were observed for both neutron star and black hole systems. The soft and hard spectral state are understood as originating from accretion via a disk which reaches inward to the compact object, in the first case, or an advection-dominated hot coronal flow/ADAF in the inner part and accretion via a disk only in the outer regions, in the second case.

In X-ray transients the change over from the hard to the soft spectrum occurs during the luminosity rise in outburst when the ADAF region disappears due to the increased accretion rate. The change back is connected with the decreasing accretion rate in outburst decline. In connection with these spectral transitions a special feature is observed, a hysteresis in the luminosity at the transition: The hard-soft transition is found at a luminosity higher by a factor of 3 to 5 than that at the soft-hard transition.

The change over from disk accretion to a hot coronal flow can be investigated by studying the interaction of a hot corona with the cool disk underneath. The location of the transition follows from the balance between mass flow rate in the thin disk and the rate at which gas evaporates into the corona. We here explain the hysteresis as caused by a different amount of Compton cooling of the corona by radiation from the inner region, very little for the hard photons of the hot inner flow at the change from hard to soft state, and more for the soft photons from the inner disk, in case of the change from soft to hard state.

1. Observations

Spectral state transitions were observed in persistent and in transient X-ray binaries (in black hole and in neutron star binaries). But the chance to observe both spectral transitions in connection with one X-ray outburst to allow a comparison of the luminosity at transition is small. Examples for observed hysteresis are: The neutron star LMXB Aql X-1, the black hole binaries GX 339-4, GS 1124-683, GS XTE J1650-500 and GS XTE J1550-564.

2. The effect of Compton cooling and heating

The structure of the corona above an inner accretion disk in LMXBs is affected by the photons from a central light source, either the innermost disk (in soft spectral state) or an extended optically thin hot region (in the hard spectral state, about 100 keV mean photon energy). An evaporation process establishes an equilibrium between the cool disk and the hot corona above (Meyer, Liu, & Meyer-Hofmeister 2000): The corona is fed by matter from the thin disk which evaporates from the cool layers underneath. The computation of the evaporation rates allows to evaluate for which mass flow rate in the accretion disk the truncation disappears and the thin disk reaches inward to the last stable orbit and the spectrum becomes soft and vice versa. The evaporation rates with Compton effect for a hard spectrum or a soft spectrum are different. This causes the hysteresis in the lightcurve.

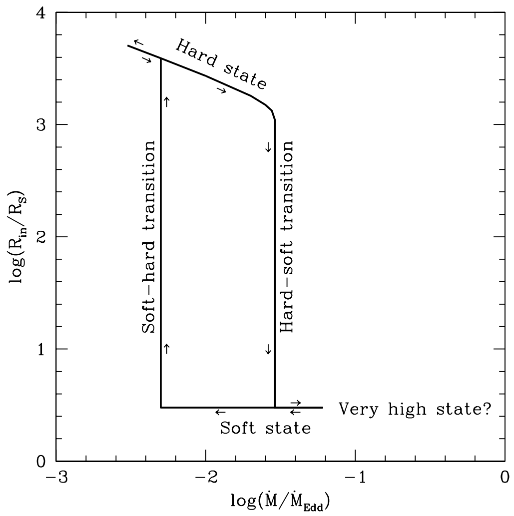

Figure 1. Changes of the disk truncation radius during a full outburst cycle

3. The hysteresis in spectral state transition

The arrows in Fig. 1 (starting from the upper left corner) show the disk inner radius changes during an outburst cycle. In quiescence the spectrum is hard. During the onset of the outburst the increasing mass accretion rate yields a decreasing truncation radius. When $\dot{M}/\dot{M}_{\rm Edd}$ reaches the critical value of the hard-soft state transition the disk extends inward to the last stable orbit. During the further rise to outburst maximum and the following decline the system stays in the soft state until the accretion rate drops to the rate at which the soft-hard transition occurs and the disk becomes truncated again. For even smaller mass accretion rates the disk truncation moves outward.

It is remarkable that our model not only gives an explanation for the observed hysteresis but also yields a quantitative estimate in agreement with observations. At the same time this result confirms the picture of the evaporation model.

A paper with full references will appear in A&A.

References

Meyer, F., Liu, B.F., & Meyer-Hofmeister, E. 2000, A&A, 361, 175